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ORIGINAL ARTICLE

Research on coating technology with wet-process sprayed mortar: waste and productivity

Investigação da tecnologia de revestimento com projeção mecânica de argamassa: desperdício e produtividade

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Abstract: The mechanical application of mortar is as an adequate solution to minimize the problems in the execution of internal and external coating of the buildings. However, few scientific studies address the gains in efficiency afforded by mechanization as well as the scarce parameters of waste, productivity and quality that could contribute to choosing this technology. This article aims to characterize the presented constructive technology and to investigate the waste of mortar (percentage of losses and consumption) and the productivity of the labor in the execution of internal and external coating for sealing in the application of wet-process sprayed mortar. Investigations were carried out in 08 construction works, which presented results of up to 150% and 0.18h/m^2 for, respectively, loss of industrialized mortar and labor productivity. Thus, the present research contributes to the advancement of the knowledge about the wet-process sprayed mortar by increasing the understanding of the technology. Other important contributions are the indicators of losses and productivity and their detailed measurement, which are efficient tools to assist the companies in the decision-making by adopting this technology as well as in the management of the activities during the execution process.

Keywords: Wet-process sprayed mortar; Loss of industrialized mortar; Labor productivity; Good business practices; Production management.

Resumo: A mecanização da aplicação da argamassa se apresenta como solução adequada para minimizar os gargalos da execução do revestimento interno e externo das edificações. No entanto, poucas pesquisas abordam os ganhos em eficiência oportunizados pela mecanização bem como escassos são os parâmetros de desperdício, produtividade e qualidade que subsidiem a escolha da tecnologia. Neste sentido, este artigo objetiva caracterizar a tecnologia construtiva e investigar o desperdício de argamassa, em termos de percentual de perdas e consumo, e a produtividade da mão de obra na execução do revestimento interno e externo de vedações na etapa de aplicação mecânica da argamassa. Foram realizadas investigações em 08 obras que apresentaram resultados de perda de argamassa industrializada de até 150% e produtividade de mão de obra de até 0,18Hh/m^2. Assim, a presente pesquisa contribui para o avanço do conhecimento acerca da projeção mecanizada de argamassa ao ampliar a compreensão da tecnologia. Os indicadores de perdas e da produtividade obtidos e o detalhamento da mensuração dos mesmos são outras importantes contribuições, as quais se

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mostram ferramentas eficientes para auxiliar as empresas na tomada de decisão pela adoção desta tecnologia bem como na gestão das atividades durante o processo de execução.

Palavras-chave: Projeção mecânica da argamassa; Perdas de argamassa industrializada; Produtividade da mão de obra; Boas práticas; Gestão da produção.

1 Introduction

As a traditional practice, the manual application of mortar coatings has been questioned in terms of obtaining better productivity indexes and the final quality of the service. In this scenario, the wet-process sprayed mortar, an internationally consecrated procedure, is presented as an adequate solution to minimize the problems in the execution of internal and external coating of the buildings, as interest in the use of this technology increases (Nakakura, 2005; Paravisi, 2008; ABCP, 2012a).

For Ruffeil et al. (2017) and Bello et al. (2017), the wet-process sprayed mortar minimizes human interference during the execution, which benefits the rationalization, the productivity, and, above all, gives greater quality and uniformity to coatings.

However, in Brazil, especially in the northeast region, this technology is not often used. This inexpressive use may be tied to a shortage of research that systematically addresses the gains in efficiency afforded by the mechanization of this activity (Paravisi, 2008; Corrêa, 2010), as well as the lack of parameters of waste, productivity, and quality that subsidize the budget, the project, and coating execution.

Asano & Barros (2017) warn that there is a paucity of data attesting to the potential of wet-process sprayed mortar to increase labor productivity and reduce material waste. For Asano (2016), the lack of parameters prevents the initiative from construction companies to adopt the technology and, consequently, impairs its improvement. Aligned with this understanding, Zanelatto et al. (2013) pointed out the need to develop detailed scientific studies on the consumption and losses of materials involved in the wet-process sprayed mortar.

It should be noted that the implementation of the technology alone does not guarantee the achievement of the mentioned advantages; it is necessary to plan the execution of the coating and the follow-up of the process (Asano & Barros, 2017; Ruffeil et al., 2017).

In view of the above, this research aims to characterize the presented constructive technology and investigate the waste of mortar and the labor productivity in the execution of internal and external coating for sealing in the application of the wet-process sprayed mortar.

2 Wet-process sprayed mortar system

The wet-process sprayed mortar is defined as the mortar transported through hoses and pneumatically launched at high velocities through a nozzle on the surface (Pinilla Melo et al., 2017; Austin et al., 2000, 2002). This system comprises three main steps: mixing, transporting, and launching the mortar to the substrate. The efficiency of the process occurs with mechanization in all stages (ABCP, 2012b). Figure 1 shows the main mortar mechanization systems available in the market.

In the wet-process sprayed mortar system the two mortar projection methods available are the pump and the projector by compressed air spray with coupled container (*canequinha*) (Figure 2). In order to choose the type of projector to be used at the construction site, the technical characteristics of the equipment must be observed, which may vary according to its pumping capacity, maximum distance (horizontal and vertical), and compatibility with the mortar to be used (Crescencio et al., 2000; Zanelatto, 2012).

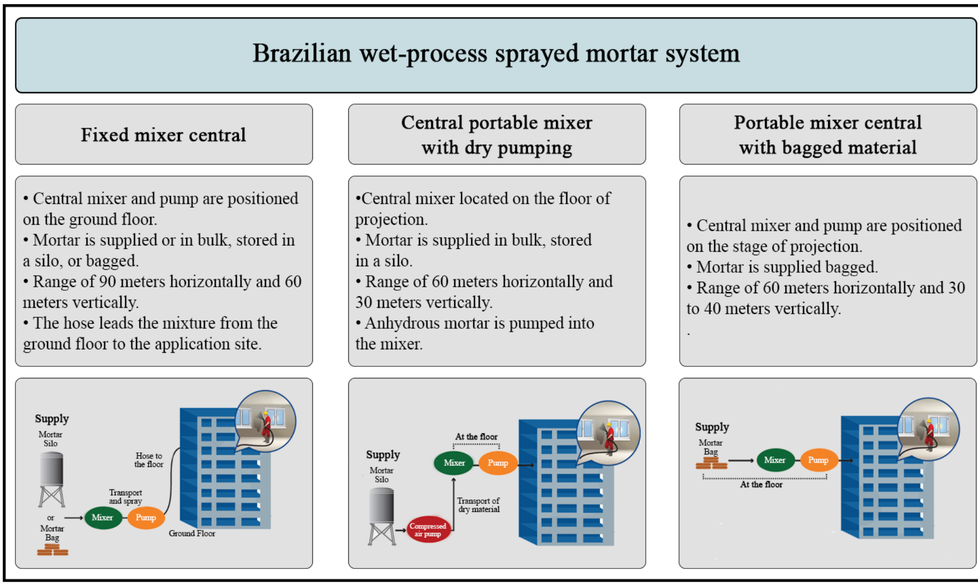

Figure 1. Wet-process sprayed mortar system. Source: Adapted from ABCP (2012b).

The projector with a coupled container does not require the use of industrialized mortar, but requires the storage of fresh mortar in a place near to the application, since the mortar is not pumped through a hose but placed directly in the container where compressed air is introduced. The projection pump is characterized by transferring the fresh mortar from the equipment chamber to the application base, which can result in higher productivity due to the continuous flow (Tamaki, 2012; Fernandes & John, 2007).

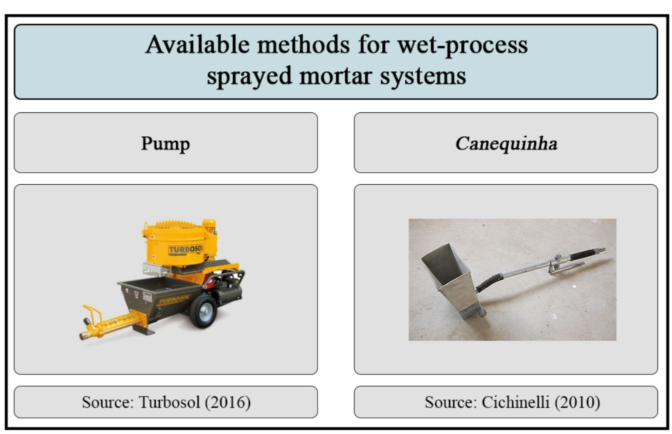

Figure 2. Wet-process sprayed mortar: methods. Source: Adapted from Turbosol (2016) and Cichinelli (2010).

In relation to the type of mortar, Giribola (2013) emphasizes the use of industrialized mortar specifically for projection, due to the possibility of hose clogging and/or damage on the parts, besides not designing the material properly.

To optimize the mortar mix transport process, Zanelatto (2012) mentions the placement of the projection pump under the outlet nozzle of the mortar mixer, so that, after being prepared in the mixer, the mortar is placed directly on the pump, eliminating a step of transporting the fresh mortar along the construction site.

In general, for the design of a wet-process sprayed mortar system, the following definitions must be made: mortar type to be used, mortar storage form, location for the mixing plant, logistics for the transport of anhydrous mortar or even if it is fresh, projection method and type of apparatus to be used for facade coating (ABCP, 2012b). Figure 3 shows the main options for each of the constituent steps of a projection system.

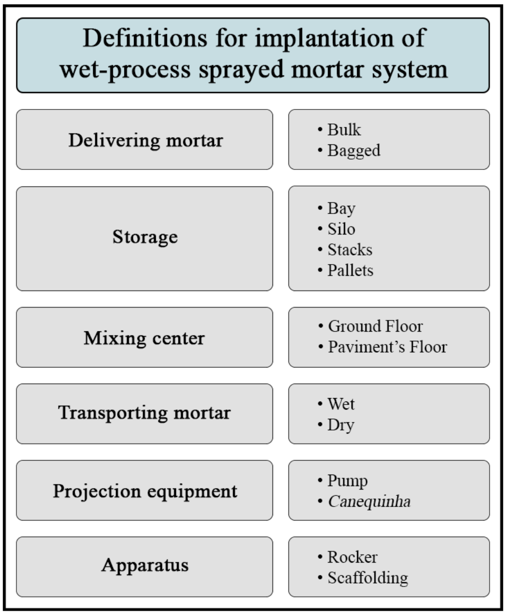

Figure 3. Definitions for implantation of wet-process sprayed mortar system. Source: Adapted from ABCP (2012b).

3 Material loss and labor productivity

Material losses are all "[…] amount of material consumed in addition to the quantity theoretically required for the product to be executed, indicated in the designs and their memorials or even in other prescriptions from the executor." The calculation of losses is performed by determining the unit consumption of real material (Souza, 2005, p. 23).

Productivity, on the other hand, is "the degree to which a system achieves a particular production goal", considering it as the efficiency in transforming inputs into outputs of a production process. In the case of the production of mortar coating, such efficiency would be associated with the transformation of human effort into coated area. Productivity can be measured by applying the Production Unitary Ratio (RUP) indicator (Souza, 2006).

Figure 4 presents the relevant equations for calculations of mortar losses and consumption as well as labor productivity.

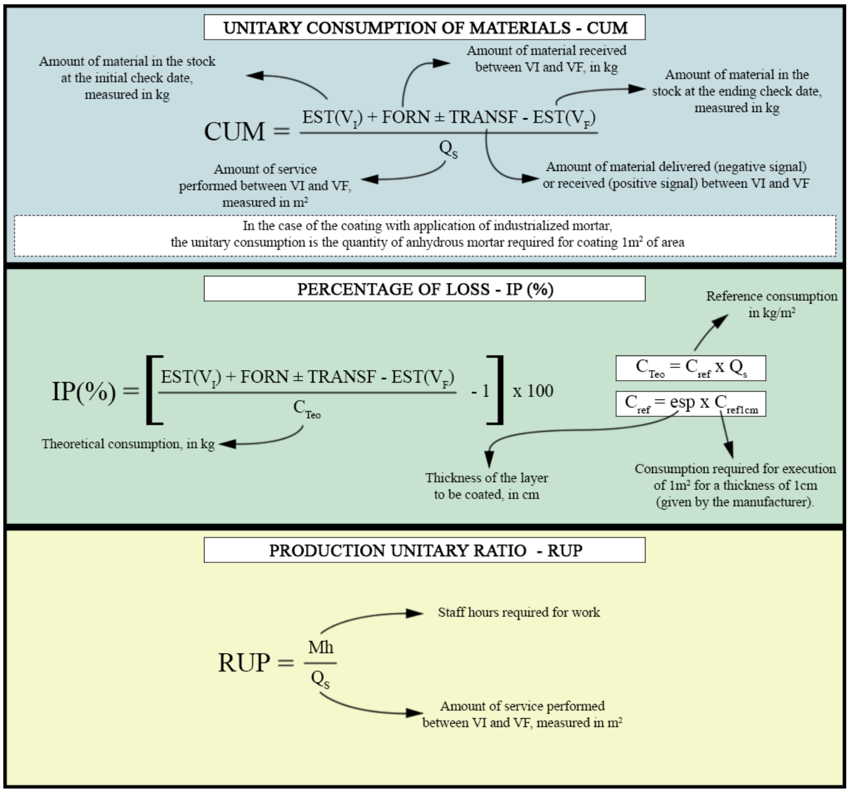

Figure 4. Calculation of losses and consumption of materials and unit production ratio. Source: Adapted from Souza (2005) and Souza (2006).

4 Parameters for waste and productivity of coating with wet-process sprayed mortar

Developed together with two housing enterprises, a 15-floor building (Case 1) and a housing complex composed of 11 blocks (Case 2), the study by Paravisi (2008) investigated the execution of external coatings with mechanical and manual application of mortar obtaining parameters of wastage and productivity. The investigated system was characterized by the use of projection bombs and industrialized mortar. For cases 1 and 2, respectively, the mixed power station was allocated on the last floor and on the ground floor, with the transportation being carried out by electric rocker and scaffolding.

Paravisi (2008) obtained mortar loss values ranging from 5.17 to 32.82% and productivity ranging from 0.88 to 1.42h/m^2. In both cases, the companies had their first experience with wet-process sprayed mortar.

Lordsleem et al. (2014) investigated waste of industrialized mortar in an enterprise with 21 floors. For the measurement of waste, the author recorded the difference between the theoretical and actual quantity of mortar consumed and the average thickness of the coating. The author obtained a mortar waste varying from 3.11 to 16.26%.

Figure 5 presents a summary of the parameters of waste of industrialized mortar in internal and external coatings obtained by Lordsleem et al. (2014) and Paravisi (2008).

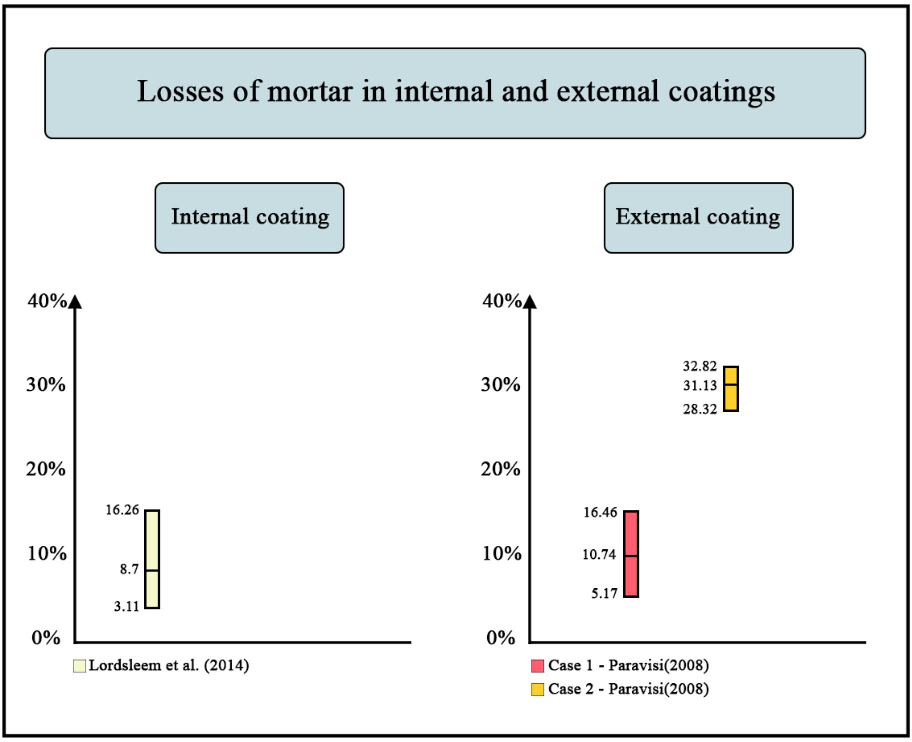

Figure 5. Parameters of losses for industrialized mortar. Source: Authors.

Costa (2013), investigated the productivity of the execution of external (Case 1) and internal (Case 2) coatings with wet-process sprayed mortar. Regarding the execution of external coatings, the evaluation was carried out in a 13-floor enterprise where workforce was subcontracted. In this case, the mortar was mixed in the projection machine on the running floor and transportation was carried out by rocker and rack. The execution of internal coatings was investigated in an enterprise of 21 floors, with its own workforce. In this case, the mortar was traditionally mixed in an *argamassadeira*. Costa (2013) obtained productivity values ranging from 0.43 to 1.44 h/m^2 for external coatings and from 0.61 to 0.62 h/m^2 for internal coatings.

Inouye (2014) studied in 10 different cases the labor productivity for the execution of internal and external coatings with wet-process sprayed mortar. The author obtained productivity of 0.23 to 0.26 h/m^2 for internal coatings and 0.65 to 0.91 h/m^2 for external coatings. The results lead the author to conclude that the use of the wet-process sprayed mortar system in coatings benefits the productivity of the workforce. Given that, in relation to the parameters presented in TCPO 14 (PINI, 2012), where the productivity varies from 0.43 h/m^2 to 1.56 h/m^2, the values obtained by Inouye (2014) were positive. Figure 6 summarizes the compiled parameters.

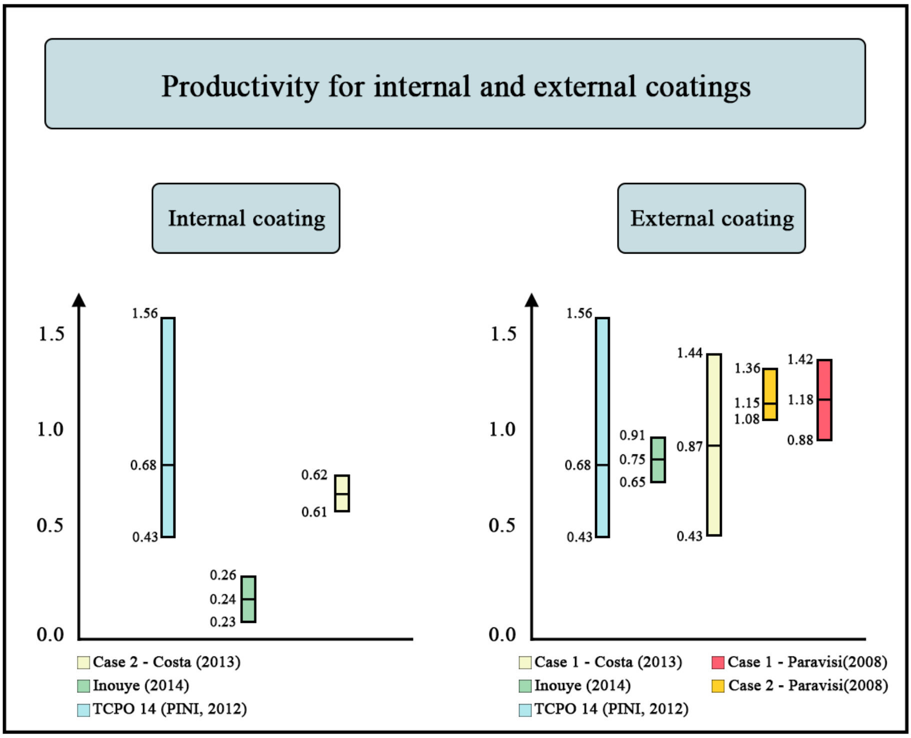

Figure 6. Parameters of labor productivity. Source: Authors.

5 Field research methodology

The methodology for carrying out the research is below in Figure 7.

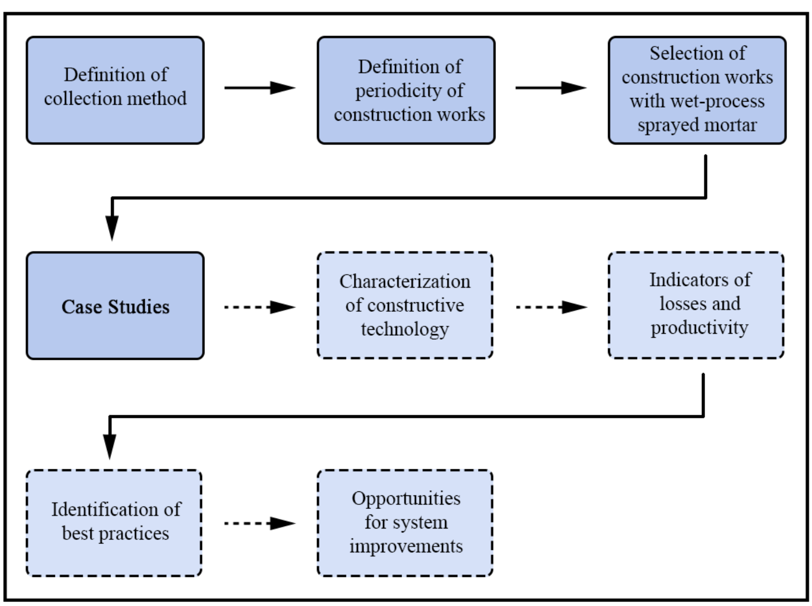

Figure 7. Methodology for field research. Source: Authors.

In order to determine the indexes of waste and productivity, the authors were the six booklets for the constructive coating technology with wet-process sprayed mortar developed by the Construction Community under the leadership of the Brazilian Portland Cement Association (ABCP).

The notebooks are designed to: characterize the enterprise; characterize the company responsible for the enterprise; measure the waste of mortar; measure labor productivity; record the deviations that affected the execution of the service (lack of service front, lack of material, lack of tool or water/energy, among others); and to present indicators of wastage and productivity. The methodology adopted by the notebooks in the measurement of waste and production will follow the guidelines presented in Figure 4.

This research was developed together with the seven construction companies and involved case studies in eight construction works. In order to maintain the confidentiality of the information collected and to safeguard the participating, the construction companies were codified through letters A, B, C, D, E, F and G and the construction works through numbers 1, 2, 3, 4, 5, 6, 7 and 8 (Figure 8). Construction works 2 and 3 belong to the same construction company.

The indexes were collected in loco through weekly technical visits to the construction works. Mortar waste indicators were investigated in works 1, 5, 6, 7 and 8 while productivity indicators were investigated in all works (Figure 8).

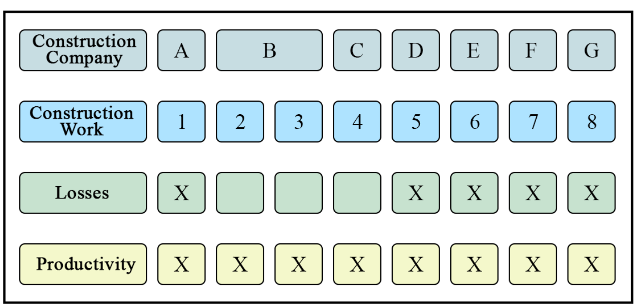

Figure 8. Construction works vs. collected indicators. Source: Authors.

The case studies included: 1) characterization of the work and the company; 2) collection, compilation and processing of data to establish the parameters of waste and productivity (the measurement of consumption of mortar, thickness of the coating layer, area performed, and hours and record of the abnormalities); 4) identification of good business practices; and 5) identification of opportunities for improvement.

The data treatment involved the determination of arithmetic mean, median, standard deviation, and coefficient of variation as well as the presentation of the values obtained through box plot graphs. It should be noted that box plots allow the identification of the medians of the results, the lower and upper quartiles (range where 50% of the data is concentrated, 25% above and 25% below the median), and maximum and minimum values.

It should be noted that in construction work 5, the unitary consumption of materials was measured by recording the number of bags of mortar added to the mixer, since the wet-process sprayed mortar used in the execution of coating was also used in other services, such as in internal coating with manual application.

6 Case studies

6.1 Characterization of the companies and construction works

All companies in this research develop housing enterprises and construction activities for private clients. The companies have ISO 9001 certification. Figure 9 presents a summary of the characteristics of the construction works related to each company.

It should be noted that construction work 7 is composed of 9 equal towers of 04 floors distributed in the same construction site. However, the indicators of waste and productivity were evaluated in one tower only.

<table>
<tr><th>Construction Work</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td>Enterprise</td><td colspan="7">Residential</td><td>Commercial</td></tr>
<tr><td>Standard</td><td colspan="7">High</td><td>Medium</td></tr>
<tr><td>Number of Towers</td><td colspan="6">1</td><td>9</td><td>3</td></tr>
<tr><td>Number of Floors</td><td>15</td><td>21</td><td>21</td><td>26</td><td>25</td><td>30</td><td>4</td><td>3</td></tr>
</table>

Figure 9. Construction works vs. features. Source: Authors.

6.2 Characterization of the wet-process sprayed mortar system

Figure 10 shows the characteristics of the wet-process sprayed mortar system in the construction works.

<table>
<tr><th colspan="2">Construction Work</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td colspan="2">Projection system</td><td colspan="3">Portable central</td><td>Fixed mixer central</td><td colspan="2">Portable central</td><td colspan="2">Fixed mixer central</td></tr>
<tr><td colspan="2">Location</td><td colspan="3">Execution floor</td><td>Ground floor</td><td colspan="2">Execution floor</td><td colspan="2">Ground floor</td></tr>
<tr><td rowspan="4">PLASTER</td><td>Type of Mortar</td><td colspan="3">Industrialized bagged</td><td>Produced on site</td><td colspan="4">Industrialized bagged</td></tr>
<tr><td>Place of Application</td><td>Internal</td><td colspan="7">External</td></tr>
<tr><td>Transport</td><td>–</td><td colspan="5">Rocker</td><td colspan="2">Facade scaffolding</td></tr>
<tr><td>Average thickness (cm)</td><td>0.7 - 1.0</td><td colspan="3">4.0 - 6.0</td><td>4.0 - 5.0</td><td>4.0 - 6.0</td><td>4.0 - 6.5</td><td>4.0 - 5.0</td></tr>
<tr><td colspan="2">Hodman/Mason ratio</td><td colspan="2">1:2</td><td>1:3</td><td>1:1</td><td>4:5</td><td>1:1</td><td>3:5</td><td>1:1</td></tr>
</table>

Figure 10. Construction works vs. wet-process sprayed mortar system. Source: Authors.

In construction works 1, 2, 3, 4 and 8, the workers already had experience with the wet-process sprayed mortar. On the other hand, construction works 5, 6 and 7 were in their first experience. Regarding the labor, construction works 4, 5, and 7 employed their own workforce. Construction work 6 used both outsource and own labor. The other companies hired outsourced companies to carry out the activity.

The construction companies first adopted a portable system with bagged material, with the mixing plant and pump positioned on the projection floor. In summary, in the portable system the main steps are: receiving the mortar; transport of bagged material to the pavement; mixture in the pavement; and application on the substrate.

In construction works 4, 7 and 8, the system was characterized as a fixed mixer, since the mortar mixture was exclusively made in the ground floor and carried (wet method) to application to the substrate. The main steps identified in this system were: receiving the mortar; transport of bagged material to the ground floor; performing the mixing on the ground floor; and transport (wet method) from the ground floor to the substrate.

Except in construction work 4, the mortar was supplied bagged and wrapped in pallets or stacked, containing the indication for mechanized application. In construction work 4, by using a mortar dosed at the site, the bulk materials were stored in nearby bays and taken to the mixing equipment.

In construction works 1, 2, 3, 5 and 6, the mortar was transported, dry, up to the mixer from the tank where it was wrapped. This route involved the use of equipment such as car pallet, for horizontal transport, and winch, for vertical transportation. In construction works 7 and 8, the bagged mortar was transferred horizontally from the bagging tank to the mixer using a skytrack forklift equipment, or telescopic manipulator.

For the mortar mix, in all the works the mixer equipment was used, in which the operator performed the water/dry material ratio, according to the production requirement. After the mixing is done, the fresh mortar is thrown directly into the projection equipment chamber. All the construction works used equipment for mortar (*argamassadeira*), except for construction work 4, where a concrete mixer was used.

In all construction works, the process mechanization starts from the stage of the mortar mixture and follows until the action of the projection in the substrate.

Construction work 4 was the only one to use the container coupled, *canequinha,* as projection equipment; the other construction works used a projection pump.

Construction works 2 to 6 used the rocker as transportation equipment. Construction works 7 and 8, however, were the only ones to use scaffolding; the time required for assembly and disassembly of this equipment affects the labor productivity, despite the fact that it makes possible the simultaneous execution of several sections along the facade.

6.3 Presentation and analysis of indicators of waste and productivity

Figure 11 shows the period of data collection performed in each construction work and the results of unitary consumption of mortar as well as cumulative and potential RUP. The values of losses and weekly productivity obtained in each construction work will be discussed in detail below.

Construction Work		1	2	3	4	5	6	7	8
Plaster		Internal	External	External	External	External	External	External	External
Analyzed period (weeks)		17	6	3	4	3	3	4	5
Unitary consumption of industrialized mortar (Kg/m²)	Minimum	15.29	–	–	–	65.88	87.47	54.25	36.54
	Medium	23.68	–	–	–	74.31	96.27	93.60	59.43
	Maximum	33.95	–	–	–	84.27	107.75	139.65	80.53
	Median	23.25	–	–	–	72.79	93.60	90.26	58.73
Cumulative productivity (h/m²)	Minimum	0.41	0.18	0.23	0.47	0.59	0.70	1.57	0.62
	Medium	0.51	0.22	0.42	0.55	0.66	1.24	2.89	0.70
	Maximum	0.58	0.22	0.49	0.61	0.82	1.56	5.91	0.82
	Median	0.51	0.24	0.42	0.55	0.66	1.45	2.04	0.69
Potencial RUPmason (Mh/m²)		0.37	0.18	0.32	0.43	0.67	0.70	1.20	0.46

Figure 11. Construction works vs. mortar consumption, cumulative and potential productivity. Source: Authors.

6.3.1 Waste of industrialized mortar in internal coatings

Figure 12 shows the results of the mortar loss indicator in the execution of internal coating with mechanical projection obtained in the construction work 1, the only case studied with execution of internal coating.

The loss data obtained in construction work 1 ranged from 27.93% to 150.02%. Due to the 45% variation coefficient, the distribution is classified as a high dispersion. According to the box plot, 50% of losses ranged from 53.26% to 122.29%.

The losses in construction work 1 were higher than those determined by Lordsleem et al. (2014), where the values presented ranged from 3.11 to 16.26%. In general, more than 50% of construction work 1 losses were greater than 53% and the average loss was 81.23%. Thus, it is considered that the losses of mortar industrialized in this work were high.

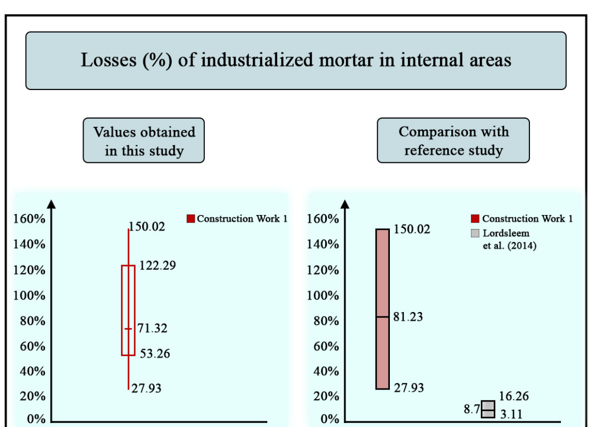

Figure 12. Losses (%) of industrialized mortar in internal areas. Source: Authors.

6.3.2 Waste of industrialized mortar in external coatings

Figure 13 shows the results of the mortar loss indicator in the execution of external coating with mechanical projection obtained in construction works 5, 6, 7 and 8.

The distribution of the data in construction works 5, 6, 7 and 8 presented a coefficient of variation of 63%, 36%, 119%, and 30%. Construction works 5, 6 and 7 are classified as high dispersion. As for construction work 8, it is classified as with medium dispersion.

In construction work 5, half of the losses ranged from 7.04% to 23.93%, data obtained at a time when the mechanized projection system was already consolidated in the company. In construction work 6, half of the losses ranged from 28.85 to 58.74%. In construction work 7, however, 50% of the losses are within the range of 6.38 to 106.02%. The low consistency of the mortar and the high thickness of the coating, greater than 04 cm, are factors that influenced the results. In construction work 8, 50% of the values are comprised between 14.14% and 21.82%.

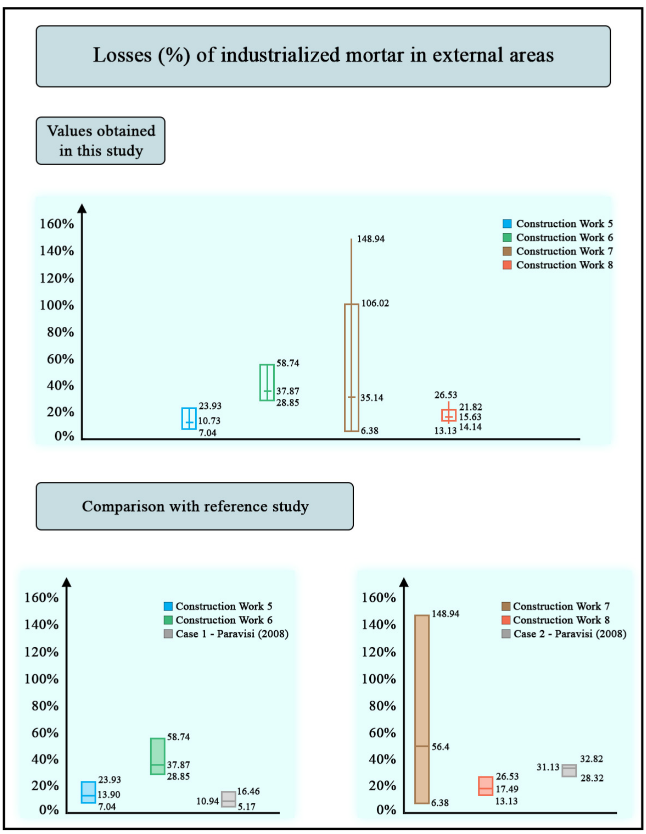

Figure 13. Losses (%) of industrialized mortar in external areas. Source: Authors.

According to Figure 13, due to similar characteristics, the losses of construction works 5 and 6 are compared to case 1 and construction works 7 and 8, to case 2, both cases from Paravisi (2008). From the comparison of the values obtained in the case studies with the literature reference parameters (Figure 13), it can be observed that the average loss of construction work 5 is close to that one found in case 1 from Paravisi (2008). On the other hand, the losses observed in construction work 6 were higher than the maximum values from construction work 5 and Paravisi (2008).

From the comparison between construction works 7 and 8 as well as case 2 from Paravisi (2008), it is observed that construction work 7 presented the lowest and highest loss indicators and construction work 8 presented the best loss result, considering the average value of all means.

Among the factors influencing the increase in the indicator of losses, it is worth to highlight: the consistency of the fresh mortar, because once it presents a marked fluidity in the act of the projection in the substrate, it can run on the surface; failures in the transport and control of bagged material, which includes losses and use in other services; and high thicknesses in the coating layer.

6.3.3 Labor productivity in internal coatings

Figure 14 shows the productivity indicator for the masons from construction work 1 and a comparison with the data from the literature.

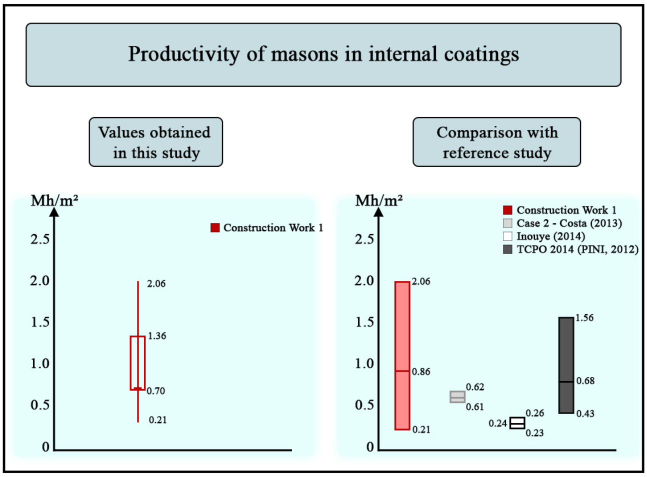

Figure 14. Productivity (h/m^2) of masons in internal coatings. Source: Authors.

The RUP of construction work 1 showed a coefficient of variation of 48%, indicating data with high dispersion. Half of the values were concentrated in the range of 0.7 to 1.36 h/m^2. The expertise of the labor, the low average thickness of the coating layer, and the application of the coating in internal areas were factors that benefited the productivity of the team.

The RUP results of construction work 1 were compared with those obtained by Costa (2013) in Case 2 and by Inouye (2014). From the comparison, it can be seen that both the mean value and the maximum value of the RUP of construction work 1 are higher than those found by the same authors. The minimum RUP of construction work 1, however, was lower than the cases with which it was compared.

6.3.4 Labor productivity in external coatings

Figure 15 presents the productivity indicator for the masons from construction work 2, 3, 4, 5, 6, 7 and 8, and compares it with the literature.

In construction works 2 and 3, belonging to the same construction company, the introduction of the mechanized projection for mortar was carried out concomitantly in order to allow the execution of the coating in two facade panels in each of the construction works.

In construction work 2, productivity ranged from 0.18 to 0.34 h/m^2, and 50% of the data ranged from 0.21 to 0.3 h/m^2. In that construction work, the median productivity was 0.21 h/m^2 while the average productivity was 0.26 h/m^2.

In construction work 3, the minimum and maximum productivity was, respectively, from 0.23 to 0.75 h/m^2. The average productivity was 0.42 h/m^2. In construction work 3, the workers" expertise and the thickness of the coating layer benefited productivity.

In construction work 4, productivity varied from 0.43 to 1.17 h/m^2 with coefficient of variation of 46%, indicating high dispersion in the data. In this case, 50% of the data were concentrated between 0.48 and 0.93 h/m^2. The median and average productivity was, respectively, 0.61 and 0.71 h/m^2.

The productivity variation in construction work 5 was 0.59 to 1.60 h/m^2 and the coefficient of variation was 54%, which shows a high dispersion in the results. Median and average productivity was 0.76 and 0.98 h/m^2, respectively. In this construction work, deviations were recorded, such as equipment breaks, clogging in the hose, delays in the transportation of bagged material to the projection pavement, and demotivation from the workers regarding the system, due to the mentioned problems.

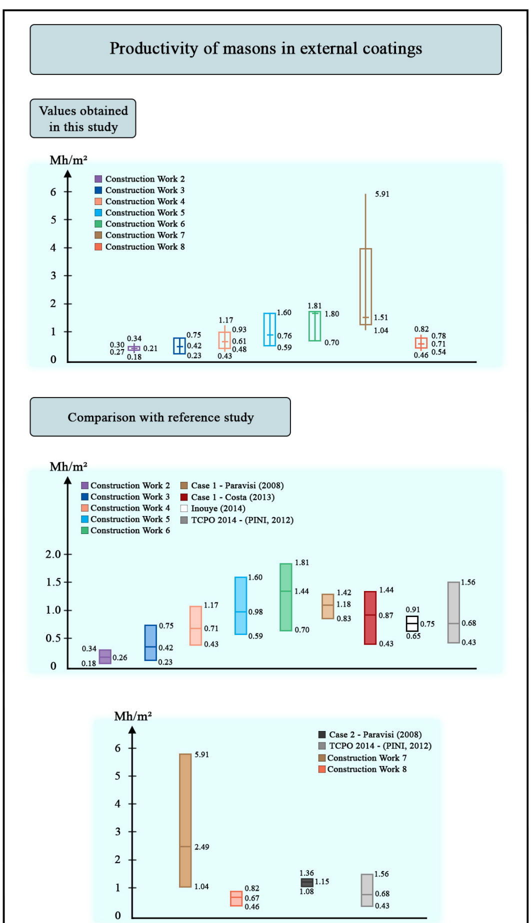

Figure 15. Productivity (h/m^2) of masons in external coatings. Source: Authors.

Productivity in construction work 6 ranged from 0.7 to 1.81 h/m^2 with a coefficient of variation of 44%, also presenting high dispersion of the data. In this construction work, deviations were recorded such as labor turnover, equipment breakdown, and demotivation from the workers, factors that potentially influenced the identified low productivity.

In construction work 7, productivity ranged from 1.04 to 5.91 h/m^2 with a coefficient of variation of 91%, indicating high dispersion. Considering the production team in this construction work (5 masons and 3 hodmen), it is understood that the productivity values were low. The extensive area of frames, trim, and corners (Figure 16), the consistency of the mortar, the equipment breakdown, the clogging in the hose, and the demotivation from the workers were potential factors influencing the productivity.

Figure 16. Facade in the construction work 7. Source: Authors.

The productivity of construction work 8 ranged from 0.46 to 0.82 h/m^2 with coefficient of variation of 20%, thus presenting data medium dispersion. In this construction work, 50% of the values were in the range of 0.54 to 0.78 h/m^2. The median productivity was 0.71 while the average was 0.67 h/m^2. The expertise of the outsourced labor force contributed to good productivity. In addition, the small number of frames, trim, and corners as well as the use of scaffolding, which facilitates the easy displacement of the workers, contributed to good results.

The productivity of construction works 2, 3, 4, 5 and 6 were compared to that obtained by Case 1 from Paravisi (2008), Case 1 from Costa (2013) and Inouye (2014), and to TCP 14 (PINI, 2012). Construction works 7 and 8 were compared to Case 2 from Paravisi (2008) and TCPO 14 (PINI, 2012). That is because these two constructions work used system with fixed mixer central positioned on the ground floor.

From the comparisons, it can be observed that construction works 2 and 3 were the ones that presented the best RUPs with minimum values lower than those presented by the reference studies.

Construction work 4, on the other hand, presented productivity compatible with those obtained by Costa (2013) and Inouye (2014), and fit within the range established by TCPO 14 (PINI, 2012).

Construction works 5 and 6 presented minimal RUPs compatible with the average RUPs from the reference studies. However, the maximum RUPs were higher than those presented by Costa (2013), Inouye (2014), and TCPO 14 (PINI, 2012).

In Figure 7, even the lowest RUP was higher than Case 2 from Paravisi (2008). In comparison with TCPO 14 (PINI, 2012), the minimal RUP of construction work 7 fell within the range of the mean and maximum RUPs established by the same authors.

With more satisfactory results, construction work 8 presented RUP consistent with that obtained by Case 2 from Paravisi (2008): the maximum RUP in construction work 8 was lower than the minimum that author. In addition, the values construction work 8 fell within the range established by TCPO 14.

The best productivity values were found in construction work 2, where the minimum RUP was 0.18 h/m². The expertise of the workforce and the small area of cloth executed contributed to this result. On the other hand, construction work 7 presented the most unfavorable productivity data, where the maximum RUP reached 5.91 h/m²; the large number of frames and trim along with mortar dosed in the site contributed to this result.

In summary, the factors that favored productivity are: the experience of the workers, especially the ones responsible for mixing the mortar; applying the mortar first to the windows; good logistics for the transportation of the bagged material. As for the factors influencing the low productivity, one may point: geometric characteristics in the executed area, referring to the number of frames, trim and corners; projection equipment breaks; hose clogging; team motivation to use the system; and lack of capacity for the team to operate the system.

Although it did not present the most satisfactory productivity results, construction work 5 developed good practices worth to mention:

- Packaging mortar from the hose, when the pump is switched off, into containers for later use (Figure 17). The stored mortar was reused in the projection and execution of finishes for the coating itself. This practice has facilitated the reduction of waste generation;

Figure 17. Mortar return containment in construction work 5. Source: Authors.

- Application of the mortar initially in the contours of the frames and later in the other areas, reducing the time of execution of the twisting and trimming of the windows;
- Packaging of waste produced during the cleaning of the equipment. The conditioned material was rested until the solid part decanted and proceeded to segregation. After that, the liquid part of the mixture was reused for cleaning the hose while the solid part was bagged and transported to the ground in a suitable place, awaiting final disposal. Such practice allows reducing the water consumption in cleaning and the scattering of waste at the site.

6.4 Opportunities for improvements in production management

Figure 18 presents the suggestions for improvement.

In this research, construction work 7 recorded the highest values of consumption of processed mortar and RUP, which may be related to the low consistency of the mortar:

when applied to the wall, it delayed reaching the point of twisting (Figure 19). Thus, it was observed that the low consistency of the mortar might influence the indicators of losses and labor productivity.

The amount of mortar produced must be consistent with labor productivity in order to avoid the accumulation of idle material in the chamber and in the hose of the projection equipment, preventing clogging in the hose. The clogging can also be caused by the lack of cleaning in the equipment.

As for transportation, difficulties were identified in the distribution and control of bagged material along the pavements, especially when it comes to the collection of materials after the end of the activities as well as the losses along the route to the mixing plant and the use of the mortar while executing other services (Figure 20).

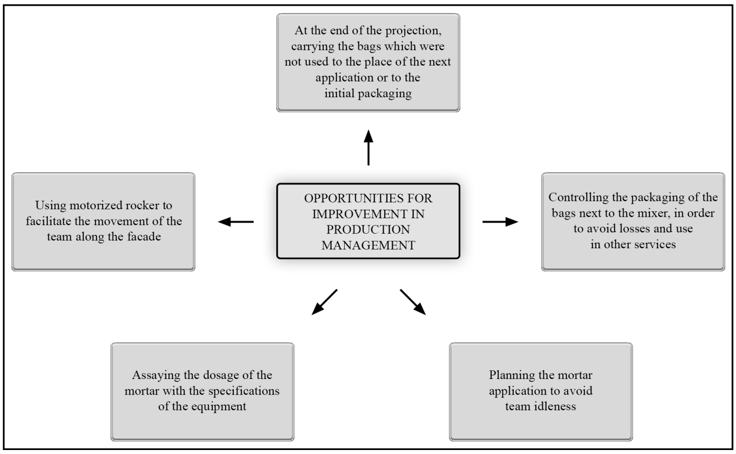

Figure 18. Opportunities for improvement in production management. Source: Authors.

Figure 19. Application of mortar with low consistency in construction work 7. Source: Authors.

It is perceived that the obstacles linked to the transport, mixing, and projection of mortar have potential influence on the waste of materials and labor productivity. This evidences the need to establish procedures for the operation of the wet-process sprayed mortar system as well as action plans to minimize possible failures.

In view of the above, it is suggested the following steps for the implementation of a projection system in a company: 1) knowing the typology of the construction work, determining the total area to be executed, thickness of the coating layer, and characteristics of the substrate; 2) knowing the layout of the site to identify the facilities for access and storage of materials; 3) knowing the equipment available at the site for the vertical and horizontal transportation of the bagged material; 4) tracing the way for the transportation of the mortar, based on the available projects, with the use of the available equipment; 5) attesting the compatibility between the available electrical energy in the construction work and the one requested in the feeding of the projection system; 6) using skilled labor to operate the projection system, and; 7) defining the form of payment of workers.

Figure 20. Deviations in the transport of mortar bags. Source: Authors.

7 Conclusions

The obtained results allowed concluding that the wet-process sprayed mortar is a technology with potential to reduce wastes and to accelerate the labor productivity. However, the benefits derived from the use of this technology are only fully achieved through proper management of the system, from the planning stage. This is due to the fact that factors linked to the mortar, the projection equipment, the transport, the cloth to be coated, and the staff that operates the system can influence the indicators of loss and productivity.

It is suggested that, for the implementation of the system, the characteristics of the typology of the construction work as well as the layout of the construction site should be known, especially with regard to transportation logistics. In addition, the workforce must be previously trained to operate the system.

Thus, the present research contributes to the advancement of the knowledge about the wet-process sprayed mortar system by increasing the understanding on the technology. The indicators of losses and productivity obtained and their detailed measurement are other important contributions, which are efficient tools to assist the companies in the decision making by adopting this technology as well as in the management of the activities during the execution process.

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